

Appendix D

Refined Procedure for the Determination of Hydrodynamic Added Masses

D-1. General

a. This appendix presents a refined procedure for finding the hydrodynamic added masses for intake towers. The refined procedure, developed by Goyal and Chopra, applies to doubly symmetric cross sections in plan. The treatment here is abbreviated. For more complete details, see Goyal and Chopra (1989). The added-mass concept is used to account for the hydrodynamic effects associated with water inside the tower and surrounding the tower during an earthquake. The procedure can be used with all of the analysis procedures presented in Appendixes B or C and is applicable for both uniform and nonuniform towers. Analytical solutions for hydrodynamic added masses are available only for circular towers (tapered or uniform) and for elliptic towers (uniform). In the following approximate procedure for tapered rectangular towers, a square or rectangular section is transformed first into an equivalent elliptical section and then into an equivalent circular section. The solution for the equivalent circular section so obtained is then taken as an approximate solution for the square or rectangular section.

b. The following sections demonstrate the calculations for hydrodynamic added masses on a rectangular intake tower. The tower is a nonuniform tower with a non-circular cross section. Figure D-1 shows the geometry of the tower. The normal pool elevation both outside and inside the tower is 1016.82 m (3336.0 ft). The water depth outside the tower H_o is 41.45 m (136 ft), and the depth inside the tower H_i is 39.62 m (130 ft). The tower is separated into discrete elements. A discrete element is an element having uniform cross-sectional properties throughout its height, both inside and outside. The tower so discretized is shown in Figure D-2. Figure D-3 depicts the basic geometry and symbols for defining the cross section. The geometry and symbols in Figure D-3 are those used in later calculations to define the hydrodynamic added masses for a noncircular section. The dimensional and cross-sectional properties of each discrete element are determined and are listed in Table D-1. For nonuniform towers of arbitrary cross section having two axes of symmetry, the hydrodynamic added mass is determined by use of the following steps:

(1) Step 1. At each discrete element, determine the cross-sectional radius $\tilde{r}_o(z)$ of the equivalent circular tower for the outside hydrodynamic mass and the equivalent cross-sectional radius $\tilde{r}_i(z)$ for the inside hydrodynamic added mass. Assume that the entire mass of the structure and of the inside and outside added masses are lumped at the midpoint of each discrete element. Determine the distance z to the midpoint of each structural mass m_s , the distance z_o to each outside added mass m_a^o and the distance z_i to each inside added mass m_a^i . The values corresponding to this procedure are shown in Table D-1. The remaining columns in Table D-1 list the cross-sectional dimensions at the level of each lumped mass and the cross-sectional area of the concrete at each of those levels. These values will be needed in later calculations. From this point onward, the calculations are tabulated in the order made. To follow the calculations for the example tower, refer to the tables of calculations given at the end of this appendix. For earthquake motions parallel to the long axis, Table D-2 shows the calculations for outside added masses and Table D-3 shows the calculations for inside added masses. The rectangular cross section at each discrete element is transformed first into an equivalent ellipse through the following relationships: the cross-sectional dimensions are shown symbolically in Figure D-3 and the actual dimensions are those listed in Table D-1.

$$\tilde{a}_o/\tilde{b}_o = a_o/b_o \quad \text{and} \quad \tilde{a}_i/\tilde{b}_i = a_i/b_i$$

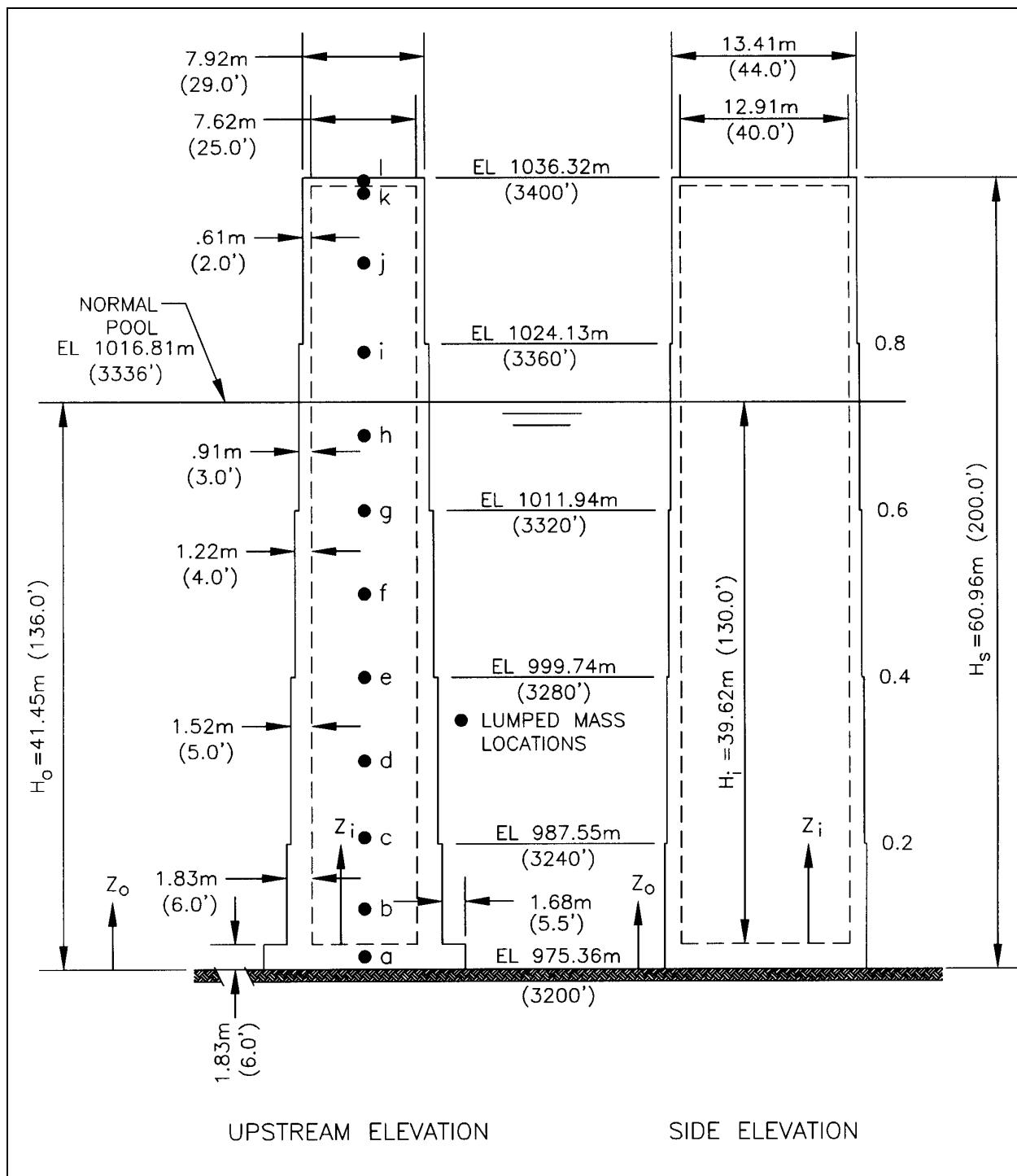


Figure D-1. Tower geometry

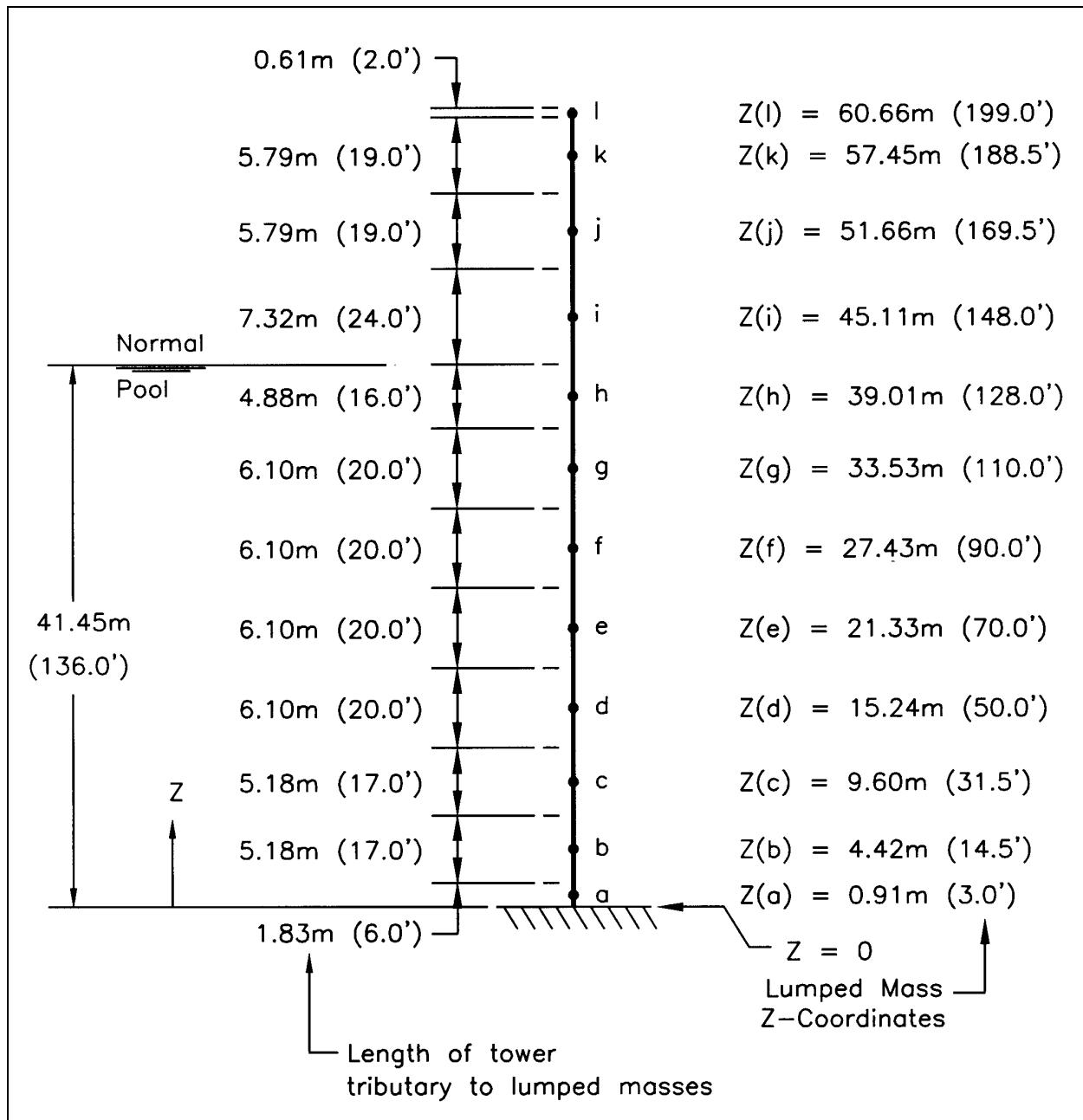


Figure D-2. Tower lumped-mass beam element idealization

where a_o , b_o , a_i , and b_i are depicted in Figure D-3 and \tilde{a}_o , \tilde{b}_o , \tilde{a}_i and \tilde{b}_i are the major and minor axes of the equivalent elliptical sections outside and inside the tower. The equivalent elliptical section is further transformed into an equivalent circular section. In towers for which $1 \leq a_o/b_o \leq 3$, the radius $\tilde{r}_o(z)$ is found through the use of Figure D-4 for the outside added mass; radius $\tilde{r}_i(z)$ is found similarly through the use of Figure D-5 for the inside added mass. Alternatively, the tabular form of Figure D-4 is given in Table D-4; it will, of course, yield the same results as Figure D-4. There is no comparable need for a tabular form of Figure D-5, since $\tilde{r}_i(z)$ can be calculated directly by the simple formula:

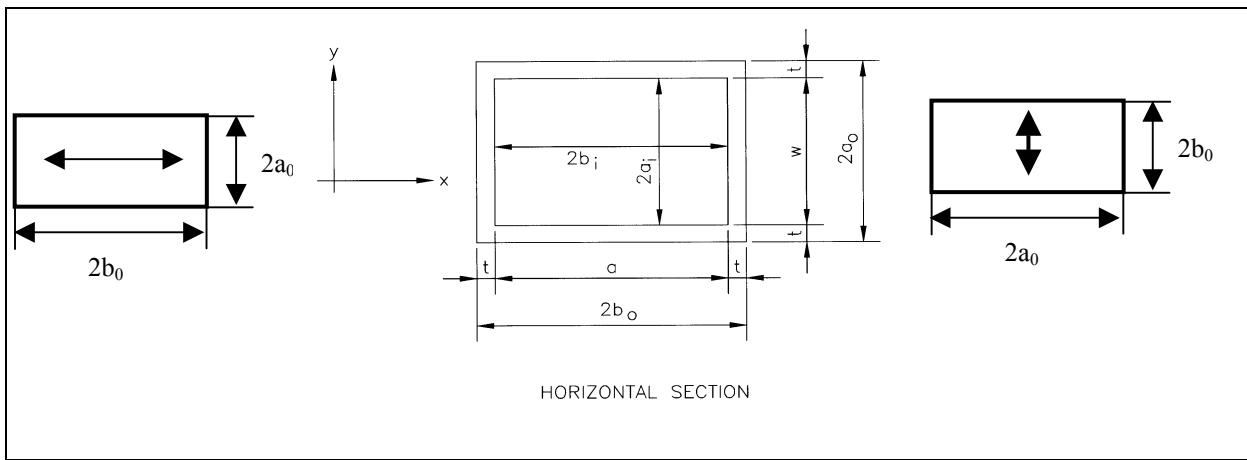


Figure D-3. Cross-sectional geometry

Table D-1
Physical Properties of the Example Tower

Mass	<i>z</i>	<i>z_o</i>	<i>z_i</i>	<i>w</i>	<i>d</i>	<i>t</i>	Outside Area <i>a_o</i>	Inside Area <i>a_i</i>
l	60.66 (199.0)	--	--	8.84 (29.0)	13.41 (44.0)	--	--	--
k	57.45 (188.5)	--	--	7.62 (25.0)	12.19 (40.0)	0.61 (2.0)	--	--
j	51.66 (169.5)	--	--	7.62 (25.0)	12.19 (40.0)	0.61 (2.0)	--	--
i	45.11 (148.0)	--	--	7.62 (25.0)	11.89 (39.0)	0.91 (3.0)	--	--
h	39.01 (128.0)	39.01 (128.0)	37.19 (122.0)	7.62 (25.0)	11.89 (39.0)	0.91 (3.0)	129.60 (1395)	90.58 (975)
g	33.53 (110.0)	33.53 (110.0)	31.70 (104.0)	7.62 (25.0)	11.58 (38.0)	1.22 (4.0)	141.02 (1518)	88.26 (950)
f	27.43 (90.0)	27.43 (90.0)	25.60 (84.0)	7.62 (25.0)	11.58 (38.0)	1.22 (4.0)	141.02 (1518)	88.26 (950)
e	21.30 (70.0)	21.30 (70.0)	19.51 (64.0)	7.62 (25.0)	11.28 (37.0)	1.52 (5.0)	152.82 (1645)	85.93 (925)
d	15.24 (50.0)	15.24 (50.0)	13.41 (44.0)	7.62 (25.0)	11.28 (37.0)	1.52 (5.0)	152.82 (1645)	85.93 (925)
c	9.60 (31.5)	9.60 (31.5)	7.27 (25.5)	7.62 (25.0)	10.97 (36.0)	1.83 (6.0)	164.99 (1776)	83.61 (900)
b	4.42 (14.5)	4.42 (14.5)	2.59 (8.5)	7.62 (25.0)	10.97 (36.0)	1.83 (6.0)	164.99 (1776)	83.61 (900)
a	0.91 (3.0)	0.91 (3.0)	0.0 (0.0)	14.63 (48.0)	14.63 (48.0)	--	214.04 (2304)	--

Note: Dimensional values are in SI units of meters, with non-SI units of feet in parentheses. Area values are in SI units of m², with non-SI units of ft² in parentheses.

w = width

d = depth

t = thickness

Table D-2
Tabular Calculations for Outside Hydrodynamic Added Mass, Example Intake Tower, Earthquake Motion Parallel to the Longitudinal Axis

Mass	<i>z</i>	<i>z_o</i>	<i>a_o</i>	<i>b_o</i>	<i>A_o</i>
h	39.01 (128.0)	39.01 (128.0)	4.72 (15.5)	6.86 (22.50)	129.60 (1395)
g	33.53 (110.0)	33.53 (110.0)	5.03 (16.5)	7.01 (23.00)	141.02 (1518)
f	27.43 (90.0)	27.43 (90.0)	5.03 (16.5)	7.01 (23.00)	141.02 (1518)
e	21.30 (70.0)	21.30 (70.0)	5.33 (17.5)	7.16 (23.50)	152.82 (1645)
d	13.24 (50.0)	15.24 (50.0)	5.33 (17.5)	7.16 (23.50)	152.82 (1645)
c	9.60 (31.5)	9.60 (31.5)	5.64 (18.5)	7.31 (24.00)	164.99 (1776)
b	4.42 (14.5)	4.42 (14.5)	5.64 (18.5)	7.31 (24.00)	164.99 (1776)
a	0.91 (3.0)	0.91 (3.0)	2.31 (24.00)	7.31 (24.00)	214.04 (2304)

Mass	<i>a_o/b_o</i>	<i>r_o/a_o</i>	<i>z_o/H_o</i>	<i>z_o/H_o</i>	$\frac{m_a^o(z)}{m_\infty^o}$	$\frac{m_\infty^o}{\rho_w a_o}$	m_∞^o	$m_a^o(z)$
h	0.689	1.18	0.135	0.941	0.49	0.88	114.11 (2379)	59.81 (1.166)
g	0.717	1.16	0.140	0.809	0.77	0.90	127.01 (2648)	97.61 (2.039)
f	0.717	1.16	0.140	0.662	0.88	0.90	127.01 (2648)	111.52 (2.330)
e	0.745	1.13	0.146	0.515	0.91	0.93	142.22 (2965)	120.11 (2.509)
d	0.745	1.13	0.146	0.368	0.94	0.93	142.22 (2965)	133.41 (2.787)
c	0.771	1.11	0.151	0.232	0.95	0.96	158.48 (3304)	150.27 (3.139)
b	0.771	1.11	0.151	0.107	0.96	0.96	158.48 (3304)	151.94 (3.172)
a	1.000	1.00	0.176	0.022	0.94	1.19	254.84 (5313)	239.05 (4.994)

Note: Mass values are in SI units of kN-sec²/m² with non-SI units of kip-sec²/ft² in parentheses. Dimensional values are in SI units of meters, with non-SI units of feet in parentheses. Area values are in SI units of m², with non-SI units of ft² in parentheses.

Table D-3
Tabular Calculations for Inside Hydrodynamic Added Mass, Example Intake Tower, Earthquake Motion Parallel to the Longitudinal Axis

Mass	Z	Z_i	a_i	b_i	A_i
h	39.01 (128.0)	37.19 (122.0)	3.81 (12.5)	5.94 (19.5)	90.56 (975)
g	33.53 (110.0)	31.70 (104.0)	3.81 (12.5)	5.79 (19.00)	88.26 (950)
f	27.43 (90.0)	25.60 (84.0)	3.81 (12.5)	5.79 (19.00)	88.26 (950)
e	21.30 (70.0)	19.51 (64.0)	3.81 (12.5)	5.64 (18.50)	85.93 (925)
d	15.24 (50.0)	13.41 (44.0)	3.81 (12.5)	5.64 (18.50)	85.93 (925)
c	9.60 (31.5)	7.77 (25.5)	3.81 (12.5)	5.49 (18.00)	274.32 (900)
b	4.42 (14.5)	2.59 (8.5)	3.81 (12.5)	5.49 (18.00)	274.32 (900)
a	0.91 (3.0)	--	--	--	--

Mass	a_i / b_i	r	r/H_i	Z_i/H_i	$\frac{m^i}{\rho_w A_i}$	$m^i(z)$
h	0.641	6.71 (22.00)	0.169	0.938	0.55	49.74 (1.039)
g	0.658	6.53 (21.44)	0.165	0.800	0.91	80.18 (1.675)
f	0.658	6.53 (21.44)	0.165	0.646	0.98	86.36 (1.804)
e	0.676	6.36 (20.87)	0.161	0.492	1.00	85.83 (1.793)
d	0.676	6.36 (20.87)	0.161	0.338	1.00	85.83 (1.793)
c	0.694	6.19 (20.32)	0.156	0.196	1.00	83.50 (1.744)
b	0.694	6.19 (20.32)	0.156	0.065	1.00	83.50 (1.744)
a	--	--	--	--	--	--

Note: Dimensional values are in SI units of meters, with non-SI units of feet in parentheses. Area values are in SI units of m^2 , with non-SI units of ft^2 in parentheses. Mass values are in SI units of $kN \cdot sec^2/m^2$ with non-SI units of $kip \cdot sec^2/ft^2$ in parentheses.

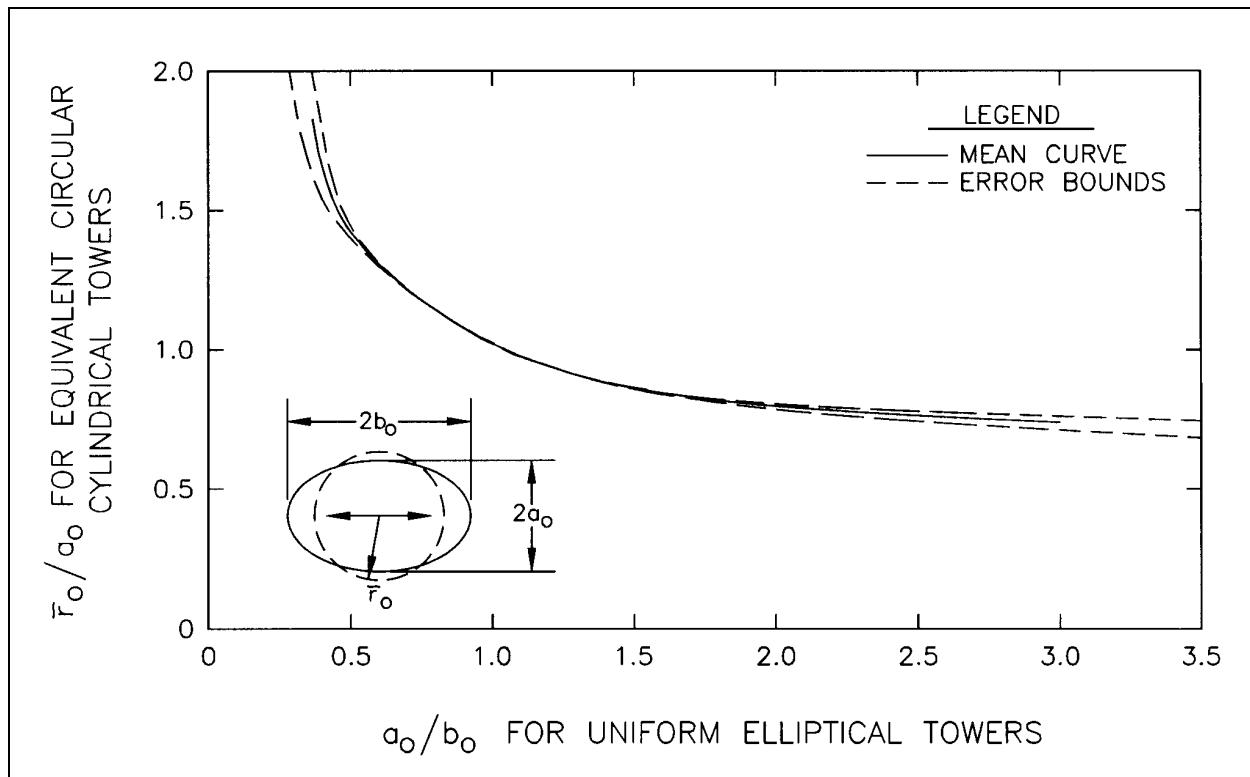


Figure D-4. Equivalent radius of circular towers for outside hydrodynamic added mass

$$\tilde{r}_i = \sqrt{\frac{A_i}{\pi} \bullet \frac{b_i}{a_i}}$$

Essentially all intake towers fall into the classification in which $a_o/b_o \leq 3$. For those structures that do not fall into this classification, a more general solution is given in Goyal and Chopra 1989. The values of the ratios $\tilde{r}_o(z)/a_o$ and $\tilde{r}_i(z)/a_i$ will yield the radii of the equivalent step-tapered circular tower at each lumped mass (or discrete element). The values of r_o/H_o and r_i/H_i are calculated from these values for use in the next step, where, at each lumped mass,

$$r_o/H_o = \tilde{r}_o/H_o \quad \text{and} \quad r_i/H_i = \tilde{r}_i/H_i$$

The values of \tilde{r}_o/H_o and \tilde{r}_i/H_i at each lumped mass are entered into the tables of calculations, Tables D-2 and D-3, for outside and inside masses, respectively. The computed values of z_o/H_o and z_i/H_i are also entered.

(2) Step 2. Determine the normalized hydrodynamic added mass for the outside water $m_a^o(z)/m_\infty^o$ and for the inside water $m_a^i(z)/\rho_w A_i$ for each discrete element. The normalized hydrodynamic added masses are determined from Table D-5 for each value of r_o/H_o and from Table D-6 for each value of r_i/H_i . The values of $m_a^o(z)/m_\infty^o$ and $m_a^i(z)/\rho_w A_i$ thus found are entered in the appropriate columns of the tables of calculations, Tables D-2 and D-3. (As a matter of interest, the curves of Figures C-7 and C-8 given earlier in Appendix C are plots of the tabulated values given in Tables D-5 and D-6. Either the curves or the tables may be used to find the normalized hydrodynamic added masses.)

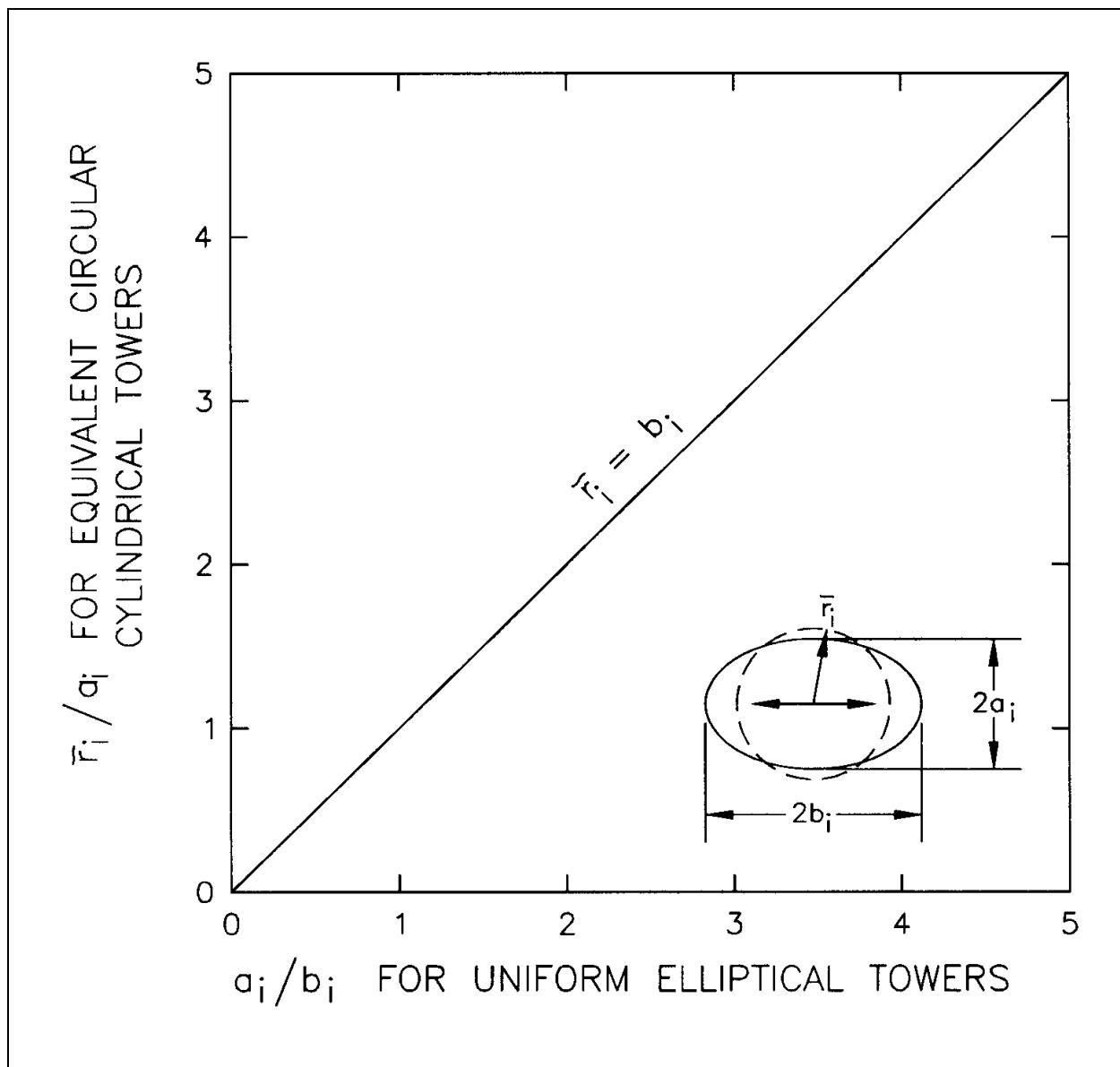


Figure D-5. Equivalent radius of circular towers for inside hydrodynamic added mass

Table D-4
Equivalent Radius of Circular Towers For Outside Hydrodynamic Added Mass (Adapted from Goyal and Chopra, 1989, Table 8-3)

a_o/b_o	\tilde{r}_o/a_o	a_o/b_o	\tilde{r}_o/a_o	a_o/b_o	\tilde{r}_o/a_o	a_o/b_o	\tilde{r}_o/a_o
0.33	1.80	1.00	1.00	1.70	0.85	2.40	0.79
0.40	1.63	1.10	0.97	1.80	0.84	2.50	0.79
0.50	1.39	1.20	0.94	1.90	0.83	2.60	0.78
0.60	1.27	1.30	0.92	2.00	0.82	2.70	0.78
0.70	1.17	1.40	0.90	2.10	0.81	2.80	0.77
0.80	1.09	1.50	0.88	2.20	0.81	2.90	0.77
0.90	1.04	1.60	0.86	2.30	0.80	3.00	0.76

Table D-5
Normalized Outside Hydrodynamic Added Mass $m_a^o(z)/m_\infty^o$ on Circular Cylindrical Towers

z/H_o	r_o/H_o									
	0.05	0.10	0.15	0.20	0.25	0.30	0.40	0.50	0.60	0.80
1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.98	0.46	0.31	0.24	0.19	0.17	0.15	0.19	0.10	0.09	0.07
0.96	0.63	0.46	0.37	0.31	0.27	0.24	0.19	0.16	0.14	0.11
0.94	0.74	0.56	0.46	0.39	0.34	0.31	0.25	0.22	0.19	0.15
0.92	0.80	0.64	0.53	0.46	0.41	0.36	0.30	0.26	0.23	0.19
0.90	0.85	0.69	0.59	0.51	0.46	0.41	0.35	0.30	0.27	0.22
0.88	0.88	0.74	0.64	0.56	0.50	0.46	0.39	0.34	0.30	0.24
0.86	0.90	0.77	0.67	0.60	0.54	0.49	0.42	0.37	0.33	0.27
0.84	0.92	0.80	0.71	0.63	0.57	0.53	0.45	0.40	0.35	0.29
0.82	0.93	0.83	0.74	0.66	0.60	0.56	0.48	0.42	0.38	0.30
0.80	0.94	0.85	0.76	0.69	0.63	0.58	0.50	0.44	0.40	0.33
0.78	0.95	0.86	0.78	0.71	0.66	0.61	0.53	0.47	0.42	0.35
0.76	0.96	0.88	0.80	0.73	0.68	0.63	0.55	0.49	0.44	0.36
0.74	0.96	0.89	0.82	0.75	0.70	0.65	0.57	0.50	0.45	0.38
0.72	0.97	0.90	0.83	0.77	0.71	0.67	0.59	0.52	0.47	0.39
0.70	0.97	0.91	0.84	0.78	0.73	0.68	0.60	0.54	0.49	0.41
0.68	0.98	0.92	0.86	0.80	0.74	0.70	0.62	0.55	0.50	0.42
0.66	0.98	0.93	0.87	0.81	0.76	0.71	0.63	0.57	0.51	0.43
0.64	0.98	0.93	0.88	0.82	0.77	0.72	0.64	0.58	0.53	0.44
0.62	0.98	0.94	0.88	0.83	0.78	0.74	0.66	0.59	0.54	0.45
0.60	0.98	0.94	0.89	0.84	0.79	0.75	0.67	0.60	0.55	0.46
0.56	0.99	0.95	0.90	0.86	0.81	0.77	0.69	0.62	0.57	0.48
0.52	0.99	0.96	0.91	0.87	0.83	0.78	0.71	0.64	0.59	0.50
0.48	0.99	0.96	0.92	0.88	0.84	0.80	0.72	0.66	0.60	0.51
0.44	0.99	0.97	0.93	0.89	0.85	0.81	0.74	0.67	0.62	0.53
0.40	0.99	0.97	0.94	0.90	0.86	0.82	0.75	0.68	0.63	0.54
0.36	0.99	0.97	0.94	0.91	0.87	0.83	0.76	0.70	0.64	0.55
0.32	0.99	0.97	0.95	0.91	0.88	0.84	0.77	0.70	0.65	0.56
0.28	0.99	0.98	0.95	0.92	0.88	0.85	0.78	0.71	0.66	0.56
0.24	0.99	0.98	0.95	0.92	0.89	0.85	0.78	0.72	0.66	0.57
0.20	0.99	0.98	0.95	0.92	0.89	0.86	0.79	0.72	0.67	0.58
0.16	1.00	0.98	0.96	0.93	0.89	0.86	0.79	0.73	0.67	0.58
0.12	1.00	0.98	0.96	0.93	0.90	0.86	0.80	0.73	0.68	0.58
0.08	1.00	0.98	0.96	0.93	0.90	0.86	0.80	0.74	0.68	0.59
0.04	1.00	0.98	0.96	0.93	0.90	0.87	0.80	0.74	0.68	0.59
0.00	1.00	0.98	0.96	0.93	0.90	0.87	0.80	0.74	0.68	0.59

(3) Step 3. For the outside water, determine the hydrodynamic added mass per unit height m_∞^o for an infinitely long tower having the same cross section throughout its length as the base of the actual tower. For the inside water, determine the mass of the water per unit height contained inside each discrete element $\rho_w A_i$. The outside hydrodynamic added mass per unit height m_∞^o of the infinitely long tower can be found through the use of Table D-7. For a rectangular cross section, the ratio $m_\infty^o / \rho_w A_o$ is read directly from Table D-7 and entered in the table of calculations, Table D-6. This ratio $m_\infty^o / \rho_w A_o$ is multiplied by $\rho_w A_o$ at each discrete element to find the value of m_∞^o at that level; this is the value of m_∞^o entered into the table of calculations for outside hydrodynamic masses, Table D-2. The mass of the water inside each discrete element is simply $\rho_w A_i$. These values are calculated as needed.

(4) Step 4. Determine the final values of the hydrodynamic added masses per unit height $m_a^o(z)$ and $m_a^i(z)$. The calculation of the outside hydrodynamic added mass is quite direct. The normalized ratio $m_a^o(z)/m_\infty^o$ found earlier and listed in the table of calculations is multiplied by the value of m_∞^o just determined. The result is the final value of the outside hydrodynamic added mass per unit height at each discrete element, $m_a^o(z)$. The calculation of the inside hydrodynamic added mass is similar. The normalized ratio $m_a^i(z)/\rho_w A_i$ found earlier and listed in the table of calculations is multiplied by the value of $\rho_w A_i$. The result is the final value of the inside hydrodynamic added mass per unit height at each discrete element $m_a^i(z)$. The values of

Table D-6
Normalized Inside Hydrodynamic Added Mass $m_a^i(z)/\rho_w A_i$ on Circular Cylindrical Towers

z/H_i	r_i /H_i									
	0.05	0.10	0.15	0.20	0.25	0.30	0.40	0.50	0.60	0.80
1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.98	0.59	0.39	0.30	0.24	0.20	0.18	0.14	0.12	0.10	0.08
0.96	0.81	0.59	0.47	0.39	0.34	0.30	0.24	0.20	0.18	0.14
0.94	0.91	0.72	0.59	0.50	0.44	0.39	0.32	0.27	0.24	0.19
0.92	0.96	0.81	0.68	0.59	0.52	0.47	0.39	0.33	0.29	0.24
0.90	0.98	0.87	0.75	0.66	0.58	0.53	0.45	0.39	0.34	0.28
0.88	0.99	0.91	0.81	0.72	0.65	0.59	0.50	0.44	0.39	0.32
0.86	0.99	0.94	0.84	0.77	0.70	0.64	0.55	0.48	0.43	0.35
0.84	1.00	0.96	0.88	0.81	0.74	0.68	0.59	0.52	0.47	0.38
0.82	1.00	0.97	0.91	0.84	0.78	0.72	0.63	0.56	0.50	0.41
0.80	1.00	0.98	0.93	0.87	0.81	0.75	0.66	0.59	0.53	0.44
0.78	1.00	0.99	0.94	0.89	0.83	0.78	0.69	0.62	0.56	0.47
0.76	1.00	0.99	0.96	0.91	0.86	0.81	0.72	0.65	0.59	0.49
0.74	1.00	0.99	0.97	0.92	0.88	0.83	0.74	0.67	0.61	0.51
0.72	1.00	0.99	0.97	0.94	0.89	0.85	0.77	0.70	0.64	0.54
0.70	1.00	1.00	0.98	0.95	0.91	0.87	0.79	0.72	0.66	0.56
0.68	1.00	1.00	0.98	0.96	0.92	0.88	0.81	0.74	0.68	0.58
0.66	1.00	1.00	0.99	0.96	0.93	0.90	0.82	0.76	0.70	0.60
0.64	1.00	1.00	0.99	0.97	0.94	0.91	0.84	0.77	0.72	0.61
0.62	1.00	1.00	0.99	0.98	0.95	0.92	0.85	0.79	0.73	0.63
0.60	1.00	1.00	0.99	0.98	0.96	0.93	0.87	0.81	0.75	0.64
0.56	1.00	1.00	1.00	0.99	0.97	0.94	0.89	0.83	0.78	0.67
0.52	1.00	1.00	1.00	0.99	0.98	0.96	0.91	0.85	0.80	0.70
0.48	1.00	1.00	1.00	0.99	0.98	0.97	0.92	0.87	0.82	0.72
0.44	1.00	1.00	1.00	0.99	0.99	0.97	0.94	0.89	0.84	0.74
0.40	1.00	1.00	1.00	1.00	0.99	0.98	0.95	0.90	0.86	0.76
0.36	1.00	1.00	1.00	1.00	0.99	0.98	0.95	0.92	0.87	0.77
0.32	1.00	1.00	1.00	1.00	0.99	0.99	0.96	0.93	0.88	0.79
0.28	1.00	1.00	1.00	1.00	1.00	0.99	0.97	0.93	0.89	0.80
0.24	1.00	1.00	1.00	1.00	1.00	0.99	0.97	0.94	0.90	0.81
0.20	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.95	0.91	0.82
0.16	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.95	0.91	0.82
0.12	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.95	0.92	0.83
0.08	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.96	0.92	0.83
0.04	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.96	0.92	0.83
0.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.96	0.92	0.83

$m_a^o(z)$ and $m_a^i(z)$ listed in Tables D-2 and D-3 are the values for the rectangular tower when the earthquake motion is parallel to the longitudinal axis. When the earthquake motion is transverse to the long axis, the dimensions a_o and b_o are reversed, as are a_i and b_i . To obtain the values of the added masses in the transverse direction, the entire computation is repeated for these new values of a_o/b_o and a_i/b_i . The procedure is identical to that for the longitudinal axis; only the numbers are different. In summary, the outside and inside hydrodynamic added masses per foot of height of the tower are shown in Table D-7 for earthquake motions in two directions. These are the values that should be added to the value of the structural mass at each discrete element to find the total magnitude of each lumped mass.

Table D-7
Summary of Added Hydrodynamic Masses (Mass per unit length of tower)

Point	Longitudinal Motion		Transverse Motion	
	Outside Added Mass	Inside Added Mass	Outside Added Mass	Inside Added Mass
h	59.81 (1.166)	49.74 (1.039)	96.27 (2.007)	63.46 (1.323)
g	97.61 (2.039)	80.15 (1.675)	164.76 (3.435)	85.67 (1.786)
f	111.52 (2.330)	86.36 (1.804)	191.19 (3.986)	88.31 (1.841)
e	120.11 (2.509)	85.83 (1.793)	210.38 (4.386)	86.00 (1.793)
d	133.41 (2.787)	85.83 (1.793)	217.33 (4.531)	86.00 (1.793)
c	150.27 (3.139)	83.50 (1.744)	230.19 (4.799)	83.65 (1.744)
b	151.84 (3.172)	83.50 (1.744)	230.19 (4.799)	83.65 (1.744)
a	239.05 (4.994)	--	238.77 (4.978)	--

Note: Mass values are in SI units of kN-sec²/m² with non-SI units of kip-sec²/ft² in parentheses.